SANY-0002-C1-US
(US99010)

APPLICATION

FOR

UNITED STATES LETTERS PATENT

TITLE: A SCHEME FOR SPREAD SPECTRUM MULTIPLE ACCESS CODING

INVENTORS: DAOBEN LI

Express Mail No.: EL515090142US

Date: February 10, 2000

A SCHEME FOR SPREAD SPECTRUM MULTIPLE ACCESS CODING

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~~This application is a continuation of PCT/CN98/00151 filed August 4, 1998.~~

Field of the Invention

The invention relates to a spread spectrum and digital multiple access wireless communications scheme, especially to a spread spectrum multiple access coding scheme applied in any digital communications system employing code division multiple access ("CDMA") and spread spectrum radio.

Background of the Invention

With the coming of the information society and the personal communications era, the demand on wireless communications technology is growing rapidly, but the frequency resources are very limited. A code division multiple access ("CDMA") technique is the only efficient way to resolve the contradiction between limited frequency resources and demand for high capacity. The capacity of traditional wireless multiple access techniques, e.g., frequency division multiple access ("FDMA") and time division multiple access ("TDMA"), is fixed once designed, i.e., additional users can not be introduced beyond that capacity limit. But CDMA is different in that the capacity is only limited by the interference level and thus results

in the advantages of large capacity and soft capacity. That is, introducing an additional user is not precluded even though it may lead to reduced signal-to-noise ratio and quality of communications. So, unlike FDMA or TDMA, an insurmountable capacity limit does not exist.

As is noted above, the capacity of a CDMA system is interference-limited, thus, whether the interference level can be controlled or not determines the system's quality. Generally, the interference in the system consists of four parts: the first is local noise, which may be reduced by applying a low noise amplifier; the second is multiple access interference ("MAI"), which comes from the other users in the system; the third is inter-code or inter-symbol interference ("ISI"); and the fourth is neighboring cell or adjacent channel interference ("ACI"). By employing well-designed multiple access codes, MAI, ISI and ACI can be reduced or even eliminated.

In any CDMA system, each user has a specific spread spectrum multiple access code for identification. Furthermore, to reduce the users' mutual interference, the spread spectrum multiple access codes must be orthogonal to each other. Indeed, orthogonality between any two users' signals is always required in any multiple access system. Given that the channel is an ideal linear time-invariant system, and accurate synchronization is realized in the system, then orthogonality between any two users' signals

can be achieved. Unfortunately, there is no such ideal channel in practice. Besides, it is quite difficult to maintain strict synchronization. That is why it is important to employ a good multiple access technique. As for a CDMA technique, well designed multiple access codes are the root of the system.

It is known that the wireless channel is a typical random time-varying channel, in which there exists not only random frequency dispersion (Doppler frequency shift) but also random time dispersion (multi-path propagation). The former introduces time selective fading to the received signals, i.e., the received signal's frequency varies randomly with time. The latter introduces frequency selective fading to the received signals, i.e. different frequency spectrum components of the received signal vary differently with time. The fading deteriorates the system's performance seriously and at the same time, reduces the system's capacity. This is especially true for the channel's time dispersion, which is caused by multi-path propagation: it prevents signals from arriving simultaneously, so ISI and MAI are caused and the system's capacity is drastically reduced. When the relative time delay between signals is zero, it is quite easy to achieve orthogonality between signals, indeed any orthogonal codes can meet that requirement, but when the relative delay between signals is non-zero, it becomes very difficult to

do so. In fact, it has been proven that there are no such spread spectrum multiple access codes in binary, finite and even complex number spaces. In particular, MAI and ISI contradict one another so that smaller MAI leads to larger ISI and vice versa.

Therefore, the distinction between different CDMA systems lies mainly in the selected multiple access codes, i.e. in a good system, ISI and MAI must both be small, otherwise they must be larger.

Existing CDMA systems have either very low efficiency or have very short communications distance for example about several hundred meters or do nothing to MAI and ISI and then all that can be done is to alleviate them by using relatively good multiple access codes.

Summary of the Invention

The aim of the invention is to present a new, simpler, clearer and faster design scheme of spread spectrum multiple access codes. Based on the scheme, both MAI and ISI in the corresponding CDMA system can be controlled and thus a digital wireless communications system with large capacity can be constructed.

Ideal spread spectrum multiple access codes should satisfy the two main conditions below:

First, each code's auto-correlation function should be an ideal impulse function, i.e. the function should be zero everywhere except at the origin. From the view of

orthogonality, each code should be orthogonal to its own relative time delay version unless the relative time delay is zero;

Second, the cross-correlation function between any two codes should be zero everywhere. From the view of orthogonality, each code should be orthogonal to all the other codes with any relative time delay (including the zero delay).

To elaborate, we denote the auto-correlation values at the origin as the main-lobe value, while the auto-correlation values not at the origin, as well as the cross-correlation values are denoted as side-lobe values. For an ideal CDMA system, the side-lobe values of all the auto-correlations and cross-correlations should be zero. For a practical system, however, it is impossible to satisfy that condition. In this case, all that can be done is to try to make the values of the side-lobes as small as possible (or the main-lobe to side-lobe value ratio as large as possible) and the number of the side-lobes as few as possible. As for binary codes, the smallest non-zero side-lobe's value must be +1 or −1.

Therefore, in some embodiments of the present invention a spread spectrum multiple access coding scheme controls and reduces the side-lobes' values of the auto-correlations and cross-correlations.

In addition, a random access asynchronous communications system in which all the user stations' clocks are not controlled by base station is desirable because of its simplicity. That system, on the other hand, has a very strict requirement on the spread spectrum multiple access codes' characteristic. So, some embodiments of the present invention give an effective and practical method for such a random access asynchronous digital communications system.

The spread spectrum multiple access codes mentioned here are composed of basic pulses with normalized "1" amplitude and width and different polarities. The number of the basic pulses is determined according to such practical factors such as the number of required users, the number of available pulse compressing codes, the number of available orthogonal pulse compressing codes, the number of available orthogonal frequencies, system bandwidth, the system's highest transmission rate, etc. The intervals between the basic pulses on the time axis are all unequal and the basic pulses' positions on it are all different, which are both considered together with the basic pulses' polarities when coding.

Of all the values of the basic pulses' intervals mentioned above, only one is an odd number larger than the smallest interval's value, i.e. the coding length is odd, while the rest intervals' values are all even. Moreover,

any interval's value can not be the sum of any other two or more interval values.

According to orthogonality, the spread spectrum multiple access codes mentioned above are sorted into different code groups, in which the polarities of the basic pulses are determined by the orthogonality requirement and the sequence is sorted according to Hadamard or other orthogonal matrices, or some kind of bi-orthogonal or trans-orthogonal matrix.

The above coding method is a new CDMA spread spectrum multiple access coding scheme for a Large Area Asynchronous Wireless Communications System or Large Area Synchronous Wireless Communications System, and the code groups are named LA-CDMA codes. When doing correlation, whether it is auto-correlation or cross-correlation, and whether it is periodic correlation, or non-periodic correlation, or even mixed correlation, no two or more basic pulses can meet together besides at the origin, which ensures that the side-lobes' values are at most +1 or -1. Furthermore, there exists a zero correlation window beside the origin and the main-lobe's value equals the number of basic pulses. Therefore, the side-lobes of the auto-correlations and cross-correlations are controlled and reduced. That is, in the corresponding CDMA system, both MAI and ISI are controlled, and an ideal CDMA system without MAI and ISI

can also be realized if the zero correlation window is utilized.

The above principles lead to a new simpler, clearer and faster design scheme of spread spectrum multiple access codes for spread spectrum technology and digital multiple access technology. Based on the scheme, a CDMA system's design can be simplified and large capacity achieved, so as to solve the contradiction between the growing need for high capacity and the limited frequency resources.

Because the side-lobes of the correlations are small and smooth, MAI and ISI are unrelated to the users' access time and thus random access is permitted. Further, as long as the stability of the clocks in the user stations' transceivers meets a specific requirement, an asynchronous mode is also permitted.

In a practical design, to increase the code's duty ratio, the above mentioned basic pulse can also be formed by pulse compressing codes, which are composed of one or more binary or m-ary sequences, including frequency modulated sequences, or frequency and phase jointly modulated sequences, or frequency, phase and time jointly modulated sequences, etc.

In order to raise the transmission data rate or reduce frequency band-width, or increase the number of multiple access codes number, the codes can also be time offset and overlapped, where the shift interval should be larger than

the channel's maximum time dispersion (the maximum multi-path time delay difference). In the case that the shift interval is smaller than the channel's maximum time dispersion, the shifted version should be modulated by different orthogonal frequencies.

In order to raise the code's duty ratio and transmission data rate simultaneously as much as possible, both of the above methods can be combined, i.e. the basic pulse is composed of pulse compressing codes (including one or more binary or m-ary sequences, or frequency modulated sequences, or frequency and phase jointly modulated sequences, or frequency, phase and time jointly modulated sequences, etc.). At the same time, the codes are time offset and overlapped.

To further increase the number of multiple access codes, the above mentioned basic pulse can also be formed by orthogonal pulse compressing codes (including one or more binary or m-ary sequences, or frequency modulated sequences, or frequency and phase jointly modulated sequences, or frequency, phase and time jointly modulated sequences, etc), or the above mentioned basic pulses can be modulated by different orthogonal frequencies.

Brief Description of the Drawings

Figure 1 illustrates an example of LA-CDMA code groups (with 16 codes) mentioned in the paper.

Figure 2 is an illustration of the non-periodic auto-correlation function mentioned in the paper (for code 1 in figure 1).

Figure 3 is an illustration of the non-periodic auto-correlation function mentioned in the paper (for code 2 in figure 1).

Figure 4 is an illustration of the non-periodic cross-correlation function mentioned in the paper (for code 1 and code 2 in figure 1).

Figure 5 is an illustration of the non-periodic cross-correlation function mentioned in the paper (for code 3 and code 4 in figure 1).

Figure 6 shows the LA-CDMA codes formed by the relative coding pulse compressing method mentioned in the paper.

Figure 7 shows the LA-CDMA codes formed by the absolute coding pulse compressing method mentioned in the paper.

Figure 8 shows the time offsetting and overlapping method to raise the code's duty ratio mentioned in the paper.

Figure 9 shows a diagram of a class of receiver.

Detailed Description

An explanation of the invention with the attached figures is presented below.

Figure 1 is a simple LA-CDMA orthogonal code group including 16 access code words that can be used by 16 users simultaneously. Each code word consists of 16 "±" basic pulses. The period of this code group is 847. The intervals between pulses are respectively: 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 60, 62, 68, 72, 76 and 39. The polarities of the pulses ensure orthogonality between the codes.

Figure 2 and Figure 3 are non-cyclic auto-correlation curves for code 1 and code 2 in Figure 1 respectively. Cross-correlation functions between other pairs of codes have quite similar shapes so that side lobes may equal a value chosen from +1, -1 or 0.

The correlation functions of any other LA-CDMA codes have quite similar shapes, and the only possible difference lies in polarities and positions of side lobes. The features of this code are described as follows:

1) Main lobe value of auto-correlation function equals the number of basic pulses, and also equals the number of orthogonal code words in the code group.
2) There are only three possible values of side lobes in the auto-correlation and cross-correlation function: +1, -1 or 0.
3) A zero correlation window in the auto-correlation and cross-correlation function or around the

origin exists, and its magnitude is equal to 1 plus two times of the minimal interval between basic pulses.

So it can be concluded that the LA-CDMA code group that is designed according to this invention can control and in some embodiments minimize the side lobes of the auto-correlation and cross-correlation function. This enables the CDMA system to control and minimize MAI and ISI simultaneously.

Table 1 and Table 2 below respectively list minimum periods of LA-CDMA codes of 16 basic pulses and 32 basic pulses under the conditions of various minimal basic pulse intervals, in order to make it convenient for choosing.

Table 1
Periods and minimum intervals of 16-pulse LA-CDMA codes

minimum interval	minimum period	Minimum Interval	minimum period	minimum interval	minimum period	minimum interval	minimum period
38	847	40	897	42	905	44	923
46	959	48	995	50	1065	52	1049
54	1081	56	1117	58	1145	60	1179
62	1213	64	1247	66	1269	68	1303
70	1337	72	1379	74	1395	76	1427
78	1461	80	1495	82	1529	84	1563
86	1587	88	1619	90	1653	92	1683
94	1715	96	1749	98	1783	100	1811
102	1843	104	1875	106	1907	108	1939
110	1971	112	2003	114	2035	116	2067
118	2099	120	2131	122	2163	124	2195

minimum interval	minimum period	Minimum Interval	minimum period	minimum interval	minimum period	minimum interval	minimum period
126	2227	128	2259	130	2291	132	2323
134	2355	136	2387	138	2419	140	2451
142	2483	144	2515	146	2547	148	2579
150	2611	152	2643	154	2675	156	2707
158	2739	160	2771	162	2803	164	2835
166	2867	168	2899	170	2931	172	2963
174	2995	176	3027	178	3059	180	3091
182	3123	184	3155	186	3187	188	3219
190	3251	192	3283	194	3315	196	3347
198	3379	200	3411	202	3443	204	3475
206	3507	208	3539	210	3571	212	3603
214	3635	216	3667	218	3699	220	3731
222	3763	224	3795	226	3827	228	3859
230	3891	232	3923	234	3955	236	3987
238	4019	240	4051	242	4083	244	4115
246	4147	248	4179	250	4211	252	4243
254	4275	256	4307				

Table 2
Periods and minimum intervals
of 32-pulse LA-CDMA codes

minimum interval	minimum period	minimum interval	minimum period	minimum interval	minimum period	minimum interval	minimum period
32	4751	34	4465	36	4447	38	4489
40	4745	42	4847	44	4889	46	5359
48	4699	50	5225	52	5125	54	5117
56	5315	58	4725	60	4687	62	4765
64	4423	66	5115	68	5059	70	5307
72	5299	74	5617	76	4955	78	5133
80	4915	82	5397	84	5499	86	4965

minimum interval	minimum period	minimum interval	minimum period	minimum interval	minimum period	minimum interval	minimum period
88	5291	90	5223	92	4837	94	5539
96	5889	98	5373	100	5319	102	5051
104	5331	106	5617	108	5991	110	5109
112	5347	114	5383	116	5127	118	4883
120	5211	122	5429	124	5737	126	5663
128	5725	130	5623	132	5725	134	5497
136	5323	138	5393	140	5465	142	5811
144	5959	146	5893	148	6331	150	6355
152	5943	154	6053	156	6075	158	6241
160	6425	162	6475	164	6267	166	6399
168	6517	170	6435	172	6491	174	6555
176	6631	178	6665	180	6751	182	6835
184	6839	186	6903	188	6971	190	7059
192	7121	194	7295	196	7521	198	7351
200	7543	202	7427	204	7521	206	7579
208	7629	210	7689	212	7739	214	7807
216	7875	218	7953	220	8031	222	8051
224	8119	226	8173	228	8239	230	8307
232	8375	234	8443	236	8499	238	8569
240	8641	242	8743	244	8747	246	8813
248	8881	250	8949	252	9011	254	9113
256	9173						

Pulse duty ratio for basic the LA-CDMA code is very low. For example, Figure 1 shows that pulse duty ratio of a 16 basic pulse code with period of 847 is merely 16/847 (=0.0189). To increase the duty ratio in a practical design, any pulse compression codes with good performance such as a Barker sequence or linear frequency modulation

code are usable to substitute for each single pulse in the basic code. In this way, as long as the received signal passes through a matched filter matched to this pulse compression code in advance, the output is the required LA-CDMA code. Several solutions for increasing pulse duty ratio included in this invention are described below:

Forming an LA-CDMA code by a relative encoding pulse compression method is shown in Figure 6. A positive pulse in the basic LA-CDMA code is generated by two consecutive pulse compression code "B"s with the same polarity, whereas a negative pulse is generated by a positive and a negative pulse compression code "B". For instance, considering a 16-pulse LA-CDMA code with a period of 847, if a 13-bit Barker sequence is chosen for the pulse compression code, then the duty ratio of the code will rise to 16X26/847 (=0.4911).

Forming an LA-CDMA code by an absolute encoding pulse compression method is shown in Figure 7. A positive pulse in the basic LA-CDMA code is generated by a pulse compression code "B", whereas a negative pulse is generated by an inverse (i.e. an inverted polarity "B") of the pulse compression code. For instance, still considering a 16-pulse LA-CDMA code with a period of 847, if a 28-bit pulse compression code is chosen to form a single pulse, then the duty ratio will rise to 16X28/847 (=0.5289); if a 38-bit

pulse compression code is chosen to form a single pulse, then the duty ratio will rise to 16X38/847 (=0.7178).

Adopting a time-offset overlapped method for increasing the duty ratio is illustrated in Figure 8, where "a" is the primitive code, "b", "c", "d" and "e" are shifted code versions after four shifts respectively, and "a+b+c+d+e" is a time-offset overlapped code. It should be noted that the time-offset value must be greater than the time dispersion range of the channel; otherwise, either adding a partial response equalizer to the receiver in order to reduce time dispersion range of channel, or adopting various orthogonal frequencies for the time-offset versions smaller than the time dispersion range of the channel, should be employed. When synchronization techniques are adopted, it is similar to a TDMA technique in that different shift versions can be used by different users. Therefore, this can increase the number of orthogonal codes greatly. In a random access system, each shifted version of the LA-CDMA code can only be used by one user, but that method can increase the user's data rate enormously without expanding system bandwidth, or can decrease system bandwidth while retaining a given data rate.

Clearly, the time-offset overlapped pulse compression method can also be employed, which is a mixture of method 1 and method 2, or a mixture of method 2 and method 3, and

further details are not needed. This method can provide the greatest increase in pulse duty ratio and information rate simultaneously (or decrease system bandwidth with data rate unaffected).

Sometimes it is inconvenient that the maximum number of users offered by the basic LA-CDMA code is determined only by the quantity of basic pulses, since the more orthogonal codes in the code group, the better. Embodiments of this invention may provide three solutions to enlarge the number of users.

The first solution is to adopt orthogonal pulse compression codes. If M pieces of orthogonal pulse compression codes can be found, then MXN orthogonal pulse compression code words can be obtained when there are N pulses in an LA-CDMA code. For example, considering a 16-pulse LA-CDMA code with a period of 847 and choosing a 32-bit orthogonal code as its pulse compression code, as there are 32 orthogonal codes in the 32-bit orthogonal pulse compression code group, there are a total of 16X32 (= 512) orthogonal code words.

The second solution is to adopt orthogonal frequencies. The simplest implementation is to utilize a general purpose FDMA/CDMA mixed technique. In this way, if M kinds of orthogonal frequencies are employed (in which intervals of frequencies are multiples of 1/T, here T is the duration of a pulse in the LA-CDMA code), then MXN

orthogonal code words can be obtained when there are N pulses in the LA-CDMA code. Introducing different orthogonal frequencies to different pulses in the LA-CDMA code, especially when the pulse compression method is employed, the finally acquired code is a compound code of the basic LA-CDMA code and the chosen pulse compression code. According to compound encoding theory, the property of a compound code is mainly determined by the code with worse performance of two elements of the compound code. Thus, when a pulse compression code is chosen poorly, the final properties of the auto-correlation and cross-correlation function will worsen. When every pulse is "isolated" by orthogonal frequencies, the pulse compression code will be "isolated" too, minimizing degradation accordingly and increasing room for choices greatly. For instance, still considering a 16-pulse LA-CDMA code with a period of 847, when 16 orthogonal frequencies are introduced and a 32-bit orthogonal code serves as the pulse compression code, a total of 16X16X32 (= 8192) orthogonal code words are obtained.

The third solution is to relax the restriction of orthogonality, i.e. to adopt quasi-orthogonality which uses imperfect orthogonal codes, to increase the number of users. For example, considering an LA-CDMA code with N pulses, as the order of N basic intervals has no affect on its auto-correlation and cross-correlation functions, it

can be arbitrary. When a code group with various orders of basic intervals is exploited at the same time, the number of users will increase enormously. This can also serve as a solution for reducing interference of adjacent service areas or channels.

Figure 9 is a block diagram of a receiver 10 for a LA-CDMA random access code division multiple access wireless system exploiting one embodiment of this invention. This system adopts 16-pulse LA-CDMA codes and 4 orthogonal frequencies, and can accommodate 64 users signaling simultaneously. The basic structures of a transmitter and a receiver may be readily ascertained once the information basic formula and modulation mode are decided. Of course, detailed implementations may entail some modification according to practical situations. For example, a receiver can be realized either by a matched filter or by a correlator. They both implement correlation operations, and have no distinction essentially. In these cases, a transmitter must generate required modulated waveforms that can be demodulated by computation. Generally, the receiver's structure is comparatively simple, such that a wireless telecommunication engineer can design it in the light of basic modulated signal waveform.

The 16-pulse LA-CDMA code with a period of 847 shown in Figure 1 is adopted as a multiple access code in this system. Moreover, it utilizes 4 orthogonal frequencies,

and each frequency's interval is the reciprocal of the basic pulse's duration. A relative coding pulse compression method is employed to generate the basic LA-CDMA code, with modulation performed using binary phase-shift keying ("BPSK"), and with a pulse compression code of a 13-bit Barker sequence, which is 1 1 1 1 1 -1 -1 1 1 -1 1 -1 1.

Users are permitted to transmit using random access, and to receive by a matched filter. The figure depicts a receiver's block diagram for a certain orthogonal frequency. An analog signal from an intermediate frequency amplifier is converted to a digital signal by an analog to digital converter 11. The system 10 detects a 13-bit Barker sequence using a pulse shape matched filter 12 that includes a 13-bit digital tap delay line 14, multipliers 16 with a 13-bit stage shift register 15, a low pass filter 18 and a weak signal rejector or small signal depressor 20. An 808-bit digital tap delay line 22 and an additional logic circuit 24, which is another part of the receiver, form a pulse position matched filter 26.

The pulse shape matched filter 26 forms pulses of the basic LA-CDMA code, while the pulse position matched filter implements a match operation on the LA-CDMA code. A pulse position matched filter can implement match operations on 16 orthogonal LA-CDMA code simultaneously.

While the present invention has been described with respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of this present invention.

What is claimed is: